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SYSTEMATIC REVIEW AND RESEARCH AGENDA ON BLOOD SUPPLY CHAIN

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ABSTRACT

With the purpose of revamping blood supply chain as a relevant research topic, we conduct a systematic review of the literature. We perform a systematic review of academic articles published in peer-reviewed international journals, mostly in the domains of blood, blood products (fresh frozen plasma, red blood cell, and platelet) and blood supply chain management. A systematic review has been developed that emphasizes the need for alignment between the key aspects of blood, blood products (fresh frozen plasma, red blood cell, and platelet) and its supply chain processes, the links between supply chain processes and supply chain strategy. A final sample of 31 articles published from 2008 to 2018 constitutes the knowledge base of the study. The scope of the research is to study the various levels and distinct forms of blood Supply Chain. Literature Survey indicates that most of the research has been conducted in the field of products having longer life cycles than the products having shorter life cycle like perishable (blood, blood products) products. The results show the publication pattern over time and provide evidence about the journals, the methodology adopted and the content elements of the blood supply chain. The research findings are applicable to a large extent for managerial decisions. There is a huge research scope available in this area as only a limited research has been done in this field. This research work and future researches in this field would be helpful for managers, students as well as academicians. After thoroughly reviewing and synthesizing important findings from existing literature, critical review and challenges are derived that highlights how blood products should be best matched with their production and logistics processes.

KEYWORDS: Review, Blood, Blood Products, Blood Supply Chain & Research Agenda

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Original Article

INTRODUCTION

Supply chain management of blood and blood products was initiated by Van Zyl (1964) in a dissertation related to perishable products. Since then, a limited number of publications have been available but the field caught more attention in recent years. In the early1980s, Nahmias (1982) studied the inventory ordering policies for perishables including blood bank management. Additionally, Prastacos (1984) reported a review paper on the theory and practice of blood inventory management. A wide range of solution methods has been implemented to improve the supply chain problems of blood products. The most commonly used techniques include: integer programming (Hemmelmayr et al., 2010; Jacobs et al., 1996; Nagurney et al., 2012; Sahin et al., 2007; Sapountzis, 1984), simulation methodology (Alfonso et al., 2012; Kamp et al., 2010; Katsaliaki and Brailsford, 2007; Katsaliaki, 2008; Kopach et al., 2008; Madden et al., 2007; Mustafee et al., 2009; Pereira, 2005; Rytila and Spens, 2006; van Dijk et al., 2009), mathematical proofs (Jagannathan and Sen, 1991; Kaspi and Perry, 1983; Pierskalla and Roach, 1972;

Prastacos, 1978), Markov dynamic programming and simulation (Haijema et al., 2007) and dynamic programming (Blake, 2009; van Dijk et al., 2009). Published research could also be classified based on the applications which generally include individual hospitals (Blake, 2009; Carden and Delli Fraine, 2005; Delen et al., 2011; Erickson et al., 2008; Haijema et al., 2009; Heddle et al., 2009; Katsaliaki, 2008; Mustafee et al., 2009; Novis et al., 2002; Pereira, 2005; Perera et al., 2009; van Dijk et al., 2009) or regional blood centers (Bosnes et al., 2005; Carden and DelliFraine, 2005; Custer et al., 2005; Davis et al., 2009; Delen et al., 2011; Denesiuk et al., 2006; Glynn et al., 2003; Haijema et al., 2007; Hemmelmayr et al., 2010; Katsaliaki, 2008; Kendall and Lee, 1980; Kopach et al., 2008; Mustafee et al., 2009; Nagurney et al., 2012; Sahin et al., 2007; van Dijk et al., 2009). As blood is a special perishable product, operations management on blood has attracted many researchers' attention, which peaked fiet in the late 1970s and early 1980s. Reviews of research work during this period can be found in Nahmias (1982) and Prastacos (1984), and later Beliën and Forcé (2012) presented a more comprehensive review of the literature on blood inventory and supply chain management. In many countries, the blood supply chain starts with the delivery or the collection of blood from the donations sites (permanent and temporary). Then, the testing and production processes are performed at blood centers and blood products including whole blood, red blood cell, plasma, and platelet are distributed to hospitals for transfusion. Blood products are used for surgeries and in the treatment of diseases including anemia, cancer, and thalassemia. Therefore, it is vital that patients receive enough and timely blood products. On the other hand, as a scarce resource with limited shelf life, blood has a complicated management so that minimizing the shortage and outdating rates is the biggest challenge in the blood supply chain management (Gunpinar & Centeno, 2015). Blood supply chain deals with the delivery of different components of blood (Red Blood Cells (RBC), White Blood Cells (WBC) and platelets suspended in a liquid substance called plasma) from the donor to the hospitals and surgery centers for patient treatment. The whole blood is collected at several collections from various donors and is then sent to blood centers. At the blood centers, blood is separated into three major blood components: RBC, plasma and platelets and are then sent to the component labs for testing for any infection such as Zika, HIV, Hepatitis A, Hepatitis B, Hepatitis C, and West Nile Virus (American Red Cross, 2017). Blood supply chain (BSC) is one of the most applicable areas in healthcare supply chain management. The main difference between business supply chain and blood supply chain is that the former has a profit-oriented basis while the latter is service oriented. Designing an efficient and effective blood supply chain plays a key role in the improvement of such supply chains.

REVIEW OF LITERATURE

Fatemeh Jafarkhana et al. (2018) analyzed Flexible and Robust Inventory-Routing (FRIR) where a blood center distributes the blood type of red blood cells to hospitals under uncertainty of demand and supply. Further, they proposed and shown to be more effective than existing methods first on benchmark instances then on a case study about Tehran Blood Transfusion Service. H. Anani et al. (2018) addressed wastage and return of blood products and examined Demand, delivery and return rates of blood products (fresh frozen plasma, red blood cell, and platelet) in health care centers and hospitals before and after the tariff. The result was the return of unused units of fresh frozen plasma and platelet to the blood transfusion organization was increased and the increase was not statistically significant, but a significant increase was observed in red blood cell return rate and return/delivery ratio. Mohammad Reza Ghatreh Samani et al. (2018) proposed a multi-objective mixed integer linear programming model for the design of an integrated blood supply chain network for disaster relief. The developed model accounted for all the special aspects of blood supply chains involving uncertain demand for blood products and their irregular supply, perishability of blood products and shortage avoidance. A hybrid framework based on the two-stage stochastic programming and possibilistic programming approaches is devised to

deal with a mixture of random and epistemic uncertainties. Some numerical experiments are conducted to validate the proposed model and its solution approach.

Zahra Hosseinifard et al. (2018) studied the significance of inventory centralization at the second echelon of a two-echelon supply chain with perishable items when the agents of the second echelon use an (S − 1, S) inventory policy. The results demonstrated that the centralization of hospitals' inventory is a key factor in the blood supply chain and can increase the sustainability and resilient of the blood supply chain. Mehdi Najafi et al. (2017) investigated blood inventory management in a hospital, and develop a mathematical model to manage blood ordering and issuing. This study accounted for the fact that blood demand and supply are uncertain, and blood transshipment is possible. A numerical experiment is designed to exhibit the deterministic model for blood inventory management results and analyze the influence of different parameters on blood inventory management. Anna c. cagliano et al. (2017) addressed blood procurement and integrated three risk management tools developed in the project management and manufacturing areas to put forward a structured approach to identify and analyze causes of risks, their manifestations and effects. Mary Dillon et al. (2017) proposed a two-stage stochastic programming model for defining optimal periodic review policies for red blood cells inventory management that focus on minimizing operational costs, as well as blood shortage and wastage due to outdating, taking into account perishability and demand uncertainty. Ahmad Zaki Mubaroka et al. (2017) developed a simple, rapid, sensitive, and label-free electrochemical assay to detect neuraminidase activity, by employing a newly synthesized latent probe AP-Neu5Ac that acts as a substrate for neuraminidase. The significance of these results showed the potential application of this method for monitoring biological status or progress in the recovery from infectious diseases caused by pathogenic neuraminidase-producing bacteria or influenza virus. Kartikeya Puranam et al. (2017) provided both a theoretical and managerial contribution to the periodic-review fixed lifetime perishable inventory literature by considering multiple independent sources of supply. One source supplied blood via a typical standing order process. The other sources were smaller lower usage hospitals that randomly transfer blood to the medical center. They proposed a solution approach that can be readily applied in practice and solve the multi-period cost minimization problem using a dynamic program. Amir H. Masoumi et al. (2017) presented supply chain network optimization pre and post-merger models. The models handled perishability of the life-saving product of blood; included both operational and discarding costs of waste captured the uncertainty associated with the demand points, as well as the expected total blood supply shortage cost and the total discarding cost at demand points. They also incorporated capacities on the links. They provided a cost efficiency (synergy) measure associated with a merger or acquisition in the blood banking industry, as well as measures capturing the expected supply shortage and surplus. Suchithra Rajendran et al. (2017) developed a mixed integer stochastic programming model under demand uncertainty. Due to the computational complexity of the problem, three heuristic rules are proposed for determining the platelet ordering policy at the hospital. The performance of these three ordering policies was compared against that of the periodic review order-up-to policy proposed in the literature using real-life data obtained from a medical center. Hamidreza Ensafian et al. (2017) developed a stochastic multi-period mixed-integer model for the collection, production, storage, and distribution of platelet in Blood Transfusion Organizations ranging from blood collection centers to clinical points. They introduced an improved approach for scenario reduction which well represents multivariate stochastic processes for uncertain parameters. Shaul K. Bar-Lev et al. (2017) addressed blood screening. The blood screening process is comprised of two phases. At the first phase, blood units are screened together in pooled groups of a certain size by the ELISA (Enzyme-Linked Immuno-Sorbent Assay) test to detect various virus-specific antibodies. The second phase of the screening process is conducted by PCR (Polymerase Chain Reaction) testing of the individual blood

units of the groups found clean by the initial ELISA phase. As a result, the shorter the testing time, the longer the residual lifetime that is left for the blood unit for future use. The controller faces a natural and well-motivated operations management problem. They proposed a new testing procedure that termed Recycled Incomplete Identification Procedure (RIIP). Harshal Lowalekara et al. (2017) showed using the TOC approach how these seemingly unrelated problems faced by the bank are in fact highly inter-related and how they all originated from a single root cause. A current reality tree (CRT) is used to identify the root cause responsible for all the major blood bank problems. A conflict resolution diagram (CRD) is constructed to identify the core-conflict(s) responsible for the blood bank's poor performance. A future reality tree (FRT) is then constructed to show how the TOC approach will help the blood bank in lowering its shortage and wastage levels. Hamidreza Ensafian et al. (2017) presented an integrated platelet supply chain where demand is age-differentiated according to the type of patient. At first, considering the apheresis method and traditional production platelet method, two mixed-integer programming models are developed based on FIFO and LIFO issuing policies. A bi-objective model has been then developed in which the first objective maximizes the freshness of the units delivered and the second minimizes the total cost. To cope with uncertain demand, a robust optimization approach is presented and the application of the proposed model is discussed in a case study. Behnam Fahimnia et al. (2017) presented a stochastic bi-objective supply chain design model for the efficient (cost minimizing) and effective (delivery time minimizing) supply of blood in disasters. The blood supply network under investigation is comprised of blood donors, mobile blood facilities, local and regional blood centers, and demand points. A hybrid solution approach, combining the ε-constraint and Lagrangian relaxation methods, is developed to solve the proposed model. Serkan Gunpinar et al. (2016), in this study, a vehicle routing problem is modeled using an integer programming approach to simultaneously identify the number of bloodmobiles to operate and minimize the distance traveled. Additionally, the model is extended to incorporate uncertainty in blood potentials and variable durations in bloodmobile visits. Optimal routings are determined using CPLEX solver and branch-and-price algorithm. Ke-Ming Wang et al. (2015) introduced the properties of inventory structure for both rescue and affected banks during blood shortage. An age-based transshipment model is developed, with two preference selection methods for transshipping blood units being presented. Additionally, this study revealed that the transshipment decision will increase the expired ratio and the overstock ratio after blood shortage. B. Zahiri et al. (2015) presented a mixed integer linear programming model to make strategic as well as tactical decisions in a blood collection system over a multi-period planning horizon. A robust possibilistic programming approach is applied to cope with the inherent epistemic uncertainty of the model’s parameters. Ismail Civelek et al. (2015) proposed a simple inventory replenishment and allocation heuristic to minimize the expected total cost over an infinite time horizon. They modeled the problem as a Markov Decision Process (MDP), derive the costs of the heuristic policy, and computationally compare this policy to extant “near optimal" policies in the literature. Seyed Mojib Zahraee et al. (2015) applied dynamic simulation and Taguchi method to design a robust blood supply chain system to improve the blood supply chain efficiency. To do the Taguchi method, four main controllable factors that are arrival rate of donors, maximum inventory level, minimum inventory level, and blood delivery policy and one noise factor which is demand variable have been chosen. Feyza Güliz et al. (2015) designed with a mobile blood collection system the primary objective of increasing blood collection levels. The Pareto set of optimum solutions is generated based on blood amounts and logistics costs, and finally, a sensitivity analysis of some important design parameters is conducted. John T. Blake et al. (2014) developed a generic framework to represent each of the ten different regional networks. The modeling approach was validated by comparing model results against data from two networks. Once validated, ten instances were developed. For each model instance, a set of experiments was conducted, from which

response surfaces were created. Non-linear optimization methods were applied to identify optimal supplier/consumer inventory policies using the response surfaces. They conclude that a generic modeling framework that is useful for regional blood supply chains but suggested that at least four instances are necessary to recoup the efforts of building a reusable model. Korina Katsaliaki et al. (2014) proposed the Blood Supply Chain Game which simulates the supply chain of blood units from donors to patients based on a real case study modeling the UK blood supply chain. The Excel-based game is an abstraction of the technical complex simulation model providing a more appropriate learning environment. This paper presented the game's background, its mathematical formulations, example teaching scenarios, and the learners' evaluation. U. Abdulwahab et al. (2014) introduced a workable model for the establishment of an inventory bank holding perishable blood platelets with a short shelf life. The model considers a blood platelet bank with eight blood types, stochastic demand, stochastic supply, and deterministic lead time. The model is evaluated in terms of four measures of effectiveness: blood platelet shortage, outdating, inventory level, and reward gained. This study confirmed that the blood platelet bank reward can be maximized by operating at the optimal inventory level, thereby minimizing the number of outdated units as well as shortages. Qinglin Duan et al. (2014) proposed a new simulation optimization (SO) framework for blood supply chain inventory management with ABO blood group compatibility. The inventory objective was to minimize the expected system outdated rate under a predetermined maximally allowable shortage level. The proposed SO framework was incorporated with a new meta-heuristic optimization algorithm, TA–TS, to identify near-optimal inventory policies in reasonably acceptable computational time. Oscar S. Silva Filho et al. (2013) presented a computational environment, which is oriented for the forecasting of blood components. The idea was to improve the planning of the inventory balance process of the blood supply chain. Oscar S. Silva Filho et al. (2012) presented a computational tool for forecasting of blood components. Such a tool allowed managers making decisions about the amount of weekly demand of packed red cells and platelets that should be delivered to hospitals. They introduced two steps of a scheme proposed for weekly forecasting of blood components. They presented software applicative developed for decision-making of blood components forecasting with respect to its main interactive resources. Jeroen Beliën et al. (2012) presented a review of the literature on inventory and supply chain management of blood products. They identified different perspectives on approaches to classifying the existing material. Each perspective is presented as a table in which the classification is displayed. The main contribution of this review was to facilitate the tracing of published work in relevant fields of interest, identifying trends and indicating which areas should be subject to future research. Bing-Nan Li et al. (2008) explored the mechanisms of decision making support in blood bank information systems. Firstly, the properties of data and decisions were examined carefully in a blood bank; then, they introduced the development of computerized decision making the support with special concerns on blood donation and transfusion service. Korina Katsaliaki (2008) conducted statistical analysis and developed a detailed discrete event simulation model with the use of data from the National Blood Service (NBS) and the supplied hospitals of a vertical part of the UK supply chain of blood products to test and identify good ordering, inventory and distribution practices. The blood supply simulation model can offer useful pieces of advice to the stakeholders of the examined system which leads to cost reductions and increased safety. Moreover, it provides a great range of experimental capabilities in a risk-free environment.

RESEARCH AGENDA AND ISSUES ADDRESSED IN BLOOD SUPPLY CHAIN

In recent years most attention with the highest frequency on sample papers reviewed has been given to manage the blood supply chain as blood is considered as a perishable product due to having a shorter life cycle. Apart from managing the blood supply chain, we have found some research papers on blood inventory management, managing blood

banks with the highest frequency. Figure 1 represented key research agenda addressed in the domain vs. frequency of research papers.

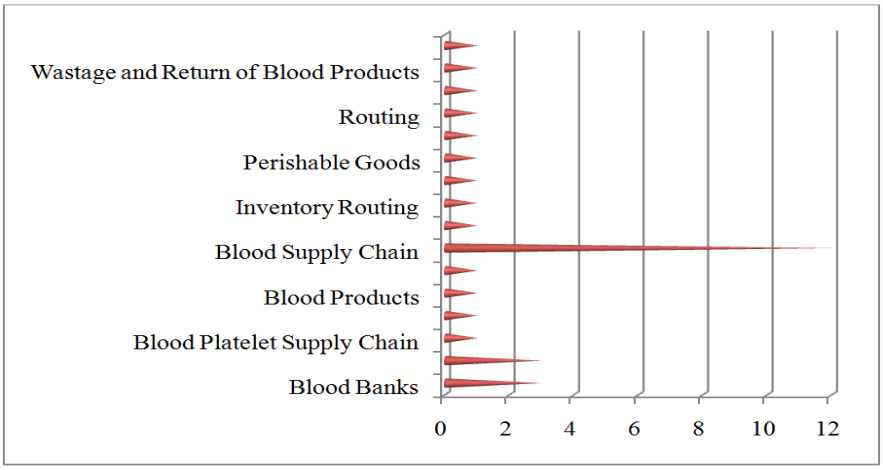

Figure 1: Key Research Agenda vs. Number of Research Paper Reviewed

We have reviewed 86 research papers in the domain of blood, blood products, and blood supply chain. A final sample of 31 articles published from a decade (2008 to 2018) constituted the knowledge base of the study. We have found some research papers on blood inventory management, managing blood banks, managing blood supply chain, preservation and management of blood platelets and platelets supply chain, procurement of blood products, preservation and management of various blood products like fresh frozen plasma, red blood cell and platelets, screening of blood and blood products, managing transshipment of blood and blood products, inventory routing problems on blood supply chain, application of operations research in blood supply chain, wastage and return of blood products and whole blood analysis. Year wise potential research issues have been addressed in the literature of the blood supply chain is presented herein the following table (Table 1).

Table 1: Year Wise Potential Research Issues Addressed in the Blood Supply Chain

Year	Research Issues Addressed- Blood Supply Chain Performance
2018	Inventory routing, Wastage, and return of blood products, Blood supply chain, Sustainability in blood supply chain
2017	Blood inventory management, Blood procurement, Blood supply chain, Whole blood analysis, Blood management, Blood banking, Platelet ordering policies, Blood platelet supply chain, Blood screening, Blood banks, Platelet supply chain, Blood Supply chain
2016	Bloodmobile routing problem
2015	Blood transshipment, Blood collection management, Blood platelet inventory management, Blood supply chain, Mobile blood donation system,
2014	Blood inventory management, Blood supply chain, Blood platelet bank, Optimization of blood supply chain
2013	Blood Supply Chain
2012	Forecasting of Blood Components, Blood Products
2008	Blood Bank Information, Blood service sector

Literature Survey indicated that most of the research in the field of managing blood and blood products has been conducted in the last five to six year. A shift has occurred in the research of products having longer life cycles to the products having a shorter life cycle like perishable Products (blood and blood products). Figure 2 represented year wise number of researches performed in the field of managing blood, blood products, and blood supply chains.

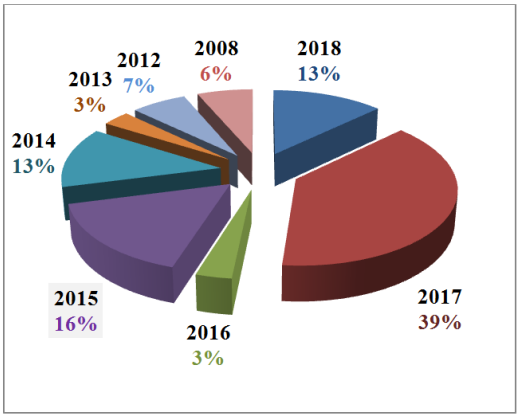

Figure 2: Year vs. Numbers of Research Issues Addressed

We performed a systematic review of academic articles published in peer-reviewed international journals, mostly in the domain of blood, blood products, and blood supply chain management. Figure 3 represented the name of peer-reviewed international journal vs. frequency of research articles reviewed in the domain.

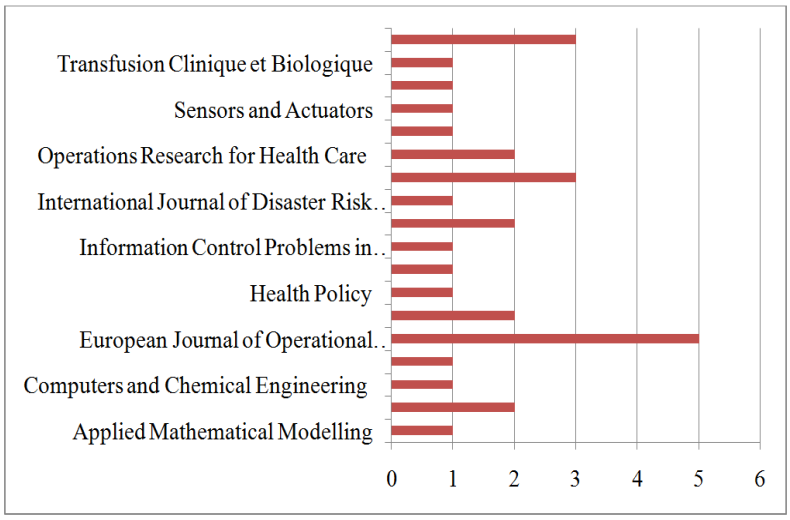

Figure 3: Name of Peer-Reviewed Journals vs. Frequency of Research Papers Reviewed

POTENTIAL ISSUES AND FUTURE RESEARCH DIRECTIONS WHILE CONSIDERING THE BLOOD SUPPLY CHAIN

Most of the researchers have been addressed various research issues in the domain related to blood inventory management, blood banks, blood supply chain, preservation and management of blood platelets and platelets supply chain, transshipment of blood and blood products, blood procurement, preservation of blood products, screening of blood, , inventory routing problems on blood supply chain, application of operations research in blood supply chain, wastage and return of blood products and whole blood analysis.

Based on our literature survey, we are recommending a list (Table 2) of potential research issues for future researches in the domain of blood, blood products supply chain.

Table 2: Future Research Directions in Blood Supply Chain

Self Life and Effect of Temperature on blood, blood products.	Logistics and inventory routing for blood, blood products
Trade-off among quality, delivery time and cost of blood, blood Products.	Strategic and environmental issues on blood, blood products
Blood inventory management system	Effect of climate change on blood, blood products
Blood inventory and pricing.	Blood replenishment in emergency, war, and disaster.
Blood replenishment to the blood banks and hospitals	Distribution of blood, blood products
Self Life and Effect of Temperature on blood, blood products.	Application of robotics and artificial intelligence in managing blood supply chain
Supply chain coordination and integration issues for blood, blood products.	Various health related issues and its impact on blood supply chain.
Blood Supply Chain Performance Measurement	Emergency preparedness system for disaster relief.

These are some of the potential research issues that can be addressed in future researches. There have been made many attempts to manage the blood, blood products supply chain, but a very few attempts, very little guidelines and literature is available to manage the enlisted research issues.

CONCLUSIONS

The present research is based on three main questions, implicitly presented in the title:

- What does blood, blood product supply chain mean?
- What is currently known about blood, blood product supply chain?
- What will come next regarding blood, blood products supply chain?

Throughout this paper, we managed to provide answers to these questions. First, we identified key research agenda in the blood supply chain vs. frequency of research paper (Figure 1) by decomposing them into various internal and external dimensions. Second, we presented a year wise number of research issues addressed (Figure 2) and Name of peer-reviewed journals vs. frequency of research papers reviewed (Figure 3). The results of an extensive systematic scientific literature review were ‑potential research issues and future research directions while considering blood, blood products supply chain. Although this study is primarily oriented towards an academic audience, it may also be useful for practitioners, who will be able to obtain the understanding of the focus of the extant research and gaining access to the most representative research areas proposed.

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